§4. Control Optimization Study of Toroidal Plasma with External Helical Magnetic Field

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The TOKASTAR-2 is a small toroidal device in which plasma confinement with tokamak configurations, stellarator configurations and tokamak-stellarator hybrid configuratins are possible[1]. The main objectives of this device are to evaluate effects of helical field application on tokamak plasma and to study effects of the plasma current on compact stellarator configuration. In FY 2011, new coils were installed; the pulsed vertical field (PVF) coils and the additional helical field (AHF) coils.

Before installation of the PVF coils, the plasma current was limited less than 100 A and its duration was limited less than 0.2 ms in tokamak operation of TOKASTAR-2 with OH coils and VF coils[2,3]. Since the time constant of eddy current decay in the vacuum vessel is about 0.35 ms and was longer than the plasma duration of TOKASTAR-2, it was difficult to control the radial position by VF coils located outside the vacuum vessel. Therefore, a pair of pulsed vertical field (PVF) coils was installed in January 2012, to be used in place of or in addition to the VF coils to improve plasma equilibrium controllability in TOKASTAR-2. In FY 2012, we successfully increased the plasma current above 1 kA using the PVF coils, but the duration of the plasma current was shorter than the duration of the positive loop voltage supplied by the ohmic heating coils. The reason is supposed to be that the time evolution of the vertical field did not match the evolution of the plasma current.

In FY 2013, the optimal PVF coil current waveform for keeping the plasma equilibrium was studied by calculation using a free-boundary equilibrium analysis code, TOSCA code. Then the capacitance and charging voltage of capacitors for PVF coils were determined to realize the optimal PVF coil current waveform by analysis using the circuit simulator, LTspice. Based on these results, optimization of tokamak plasma equilibrium control in the actual device was performed.

After optimization of tokamak operation including adjusting charging voltage of capacitors of PVF coil circuit, tokamak plasmas with high plasma current (~1.7 kA) with a long duration (~0.46 ms) were successfully obtained. An example is shown in Fig. 1. It should be noted that the duration of the positive loop voltage was shorter than that in FY 2012 because of limited number of capacitor banks. The duration of plasma current reached the whole duration of the positive loop voltage, which was mainly determined by the capacitance of the capacitor of OH coil circuit.

The radial profile of poloidal magnetic field was measured by multi-channel magnetic probe array (10 channels) for the first time in TOKASTAR-2. The initial results showed that the plasma axis was located around R = 0.115 m, namely near the center between the inboard (R = 0.065 m) and the outboard (R = 0.180 m) walls.

The AHF coils were installed to make closed flux surfaces without plasma current, together with the existing outer helical field (HF) coils[2,3]. The first series of experiments using the AHF coils was performed in January and February 2014. The currents in the toroidal field coils, HF coils, AHF coils and VF coils were determined so that the closed flux surfaces contain the EC resonance layer for a 2.45 GHz RF wave. In the experiment, increase in the plasma light intensity and decrease in fluctuations in the plasma position were observed by the fast visible camera.

In summary, progress has been made in the operation of tokamak plasmas and stellarator plasmas in TOKASTAR-2 in FY 2013. In FY 2014, we plan to continue the optimization of tokamak plasmas and stellarator plasmas with more detailed measurements of plasma parameters, and also start study on tokamak-stellarator hybrid configurations.

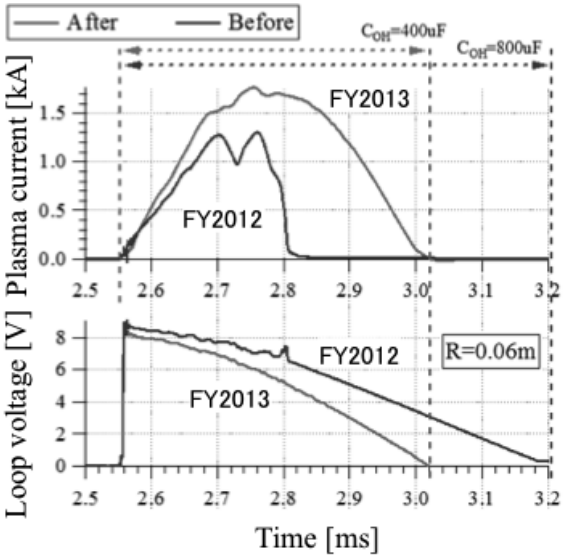

Fig. 1. Time evolution of plasma current and loop voltage in TOKASTAR-2 tokamak plasmas in FY 2012 and FY 2013.

1) Oishi, T. et al.: J. Plasma Fusion Res. SERIES **9** (2010) 69.
2) Hasegawa, M. et al.: IEEJ Transactions on Fundamentals and Materials **132** (2012) 521.
3) Hasegawa, M. et al.: Plasma Fusion Res. **7** (2012) 2402116.